

SPATIAL AND TEMPORAL VARIABILITY OF INFRARED-OBSERVABLE
PROPERTIES OF THE JOVIAN ATMOSPHERE: A PARTIAL SURVEY

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Examination of infrared characteristics of the Jovian atmosphere are made using Voyager IRIS mapping from 1979, ground-based scanning from 1979-1983, and ground-based mapping from 1983 to the present. In general, there is a strong correlation between tropospheric thermal properties and the visual cloud albedo for all observations. The Voyager IRIS maps show no strong evidence for day/night differences. Temperature differences diminish with depth in the troposphere. Temporal changes over several weeks indicate a high correlation between thermal and visual properties, although no changes in the distribution of para H_2 and ortho H_2 are seen. Stratospheric banded organization is different from the troposphere, and there is a temperature enhancement near the north magnetic pole. The spatial distributions of ammonia gas and ammonia ice absorption are different. Stratospheric temperatures exhibit seasonal hemispheric asymmetry. Other temperature changes at and below the 150-mb level correlate with changes in the Jovian visual structure. The stratospheric temperature field is uncorrelated with visual features or temperatures below the 150-mb level. Elevated temperatures are observed near both north and south magnetic pole positions. Both the meridional positions and the relative intensities of stratospheric banded organization change significantly, especially after 1982. Ground-based mapping confirms a correlation between temperatures and various measures of cloud distribution. Complex and unexpected characteristics are observed in the stratospheric temperature field; these include dramatic temporal changes on short time scales.

I want to make a quick survey of thermal infrared features and their variability over the disk and evolution in time. I'll focus on recent work John Martonchik and I have been doing on the Voyager IRIS north/south maps. Also I'll take a quick look at results of scanning of the Jovian central meridian between 1979 and 1984 and mapping of the whole disk which began in a crude form in 1983 and continues through the present. Contributing to the mapping effort are Kevin Baines, Jay Bergstralh, John Caldwell, Terry Martin, Rich Terrile, Alan Tokunaga, and Robert West.

While John and I are also looking at IRIS data for Jupiter with higher spatial resolution, I want to concentrate on the global maps whose characteristic resolution is around 14000 km. These provide a good starting point for a picture of global variations of atmospheric properties. We concentrate on maps combining data from sequences both before and after closest approach. Differences between these inbound and outbound maps appear to be below the noise of the observations. Over the longer several-week period between Voyager 1 and 2

encounters, however, recognizable changes take place. These are clearly evident in meridional maps of zonally-averaged temperatures (Fig. 1). Going deeper in the troposphere, from the 602-cm^{-1} radiances to those at shorter frequencies, strong limb darkening takes place, which also tends to suppress the appearance of detailed spatial structure. Without going into the analysis that Conrath and Gierasch (1984) presented in deriving the global variations of the ortho- H_2 and para- H_2 ratios, we can see similar morphological variations by examining the brightness temperature differences between 520 cm^{-1} and 310 cm^{-1} , similar to their primary data base. All longitudinal structure vanishes in such a map, as they described; furthermore, nearly the same distribution is revealed by Voyager 2 maps.

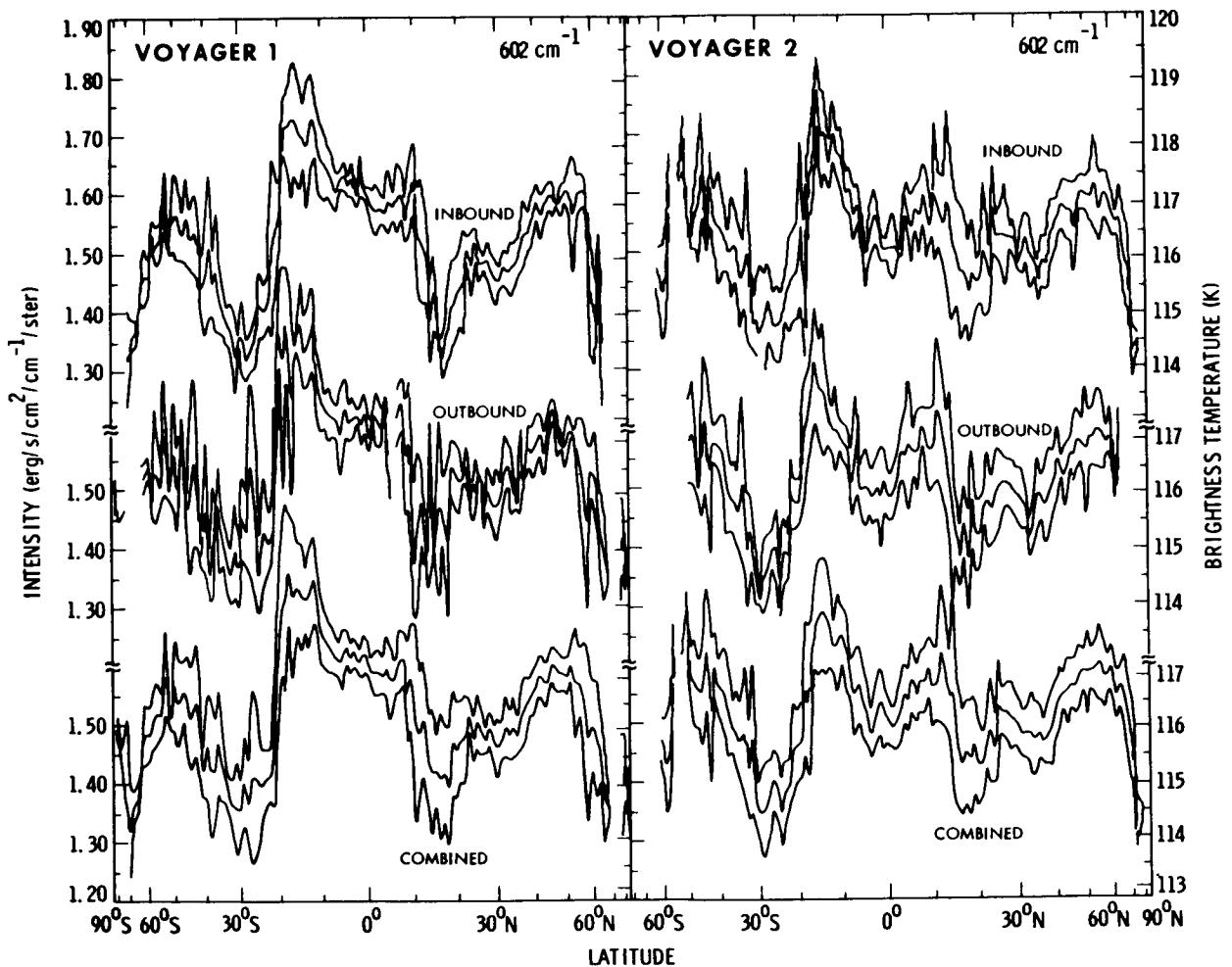


Figure 1. Plot of zonally-averaged radiances observed by Voyagers 1 and 2 at 602 cm^{-1} taken from the IRIS north/south map data. The curves plotted above and below the mean represent the excursions of one standard deviation. Breaks in the curve result from the absence of data in some of the 128 bins corresponding to cosine of latitude.

Longitudinal features also tend to disappear for maps of stratospheric thermal radiance. The meridional organization also looks different from that given by the shorter frequencies sensitive to tropospheric temperatures: three bands appear, one near the equator and two at mid-latitudes. One major longitudinal feature is the hot spot which is correlated with the general position of the north magnetic pole. Nothing is seen at the south, either because the south polar feature was not present at the time of each encounter or because it was over the horizon (all Voyager 1 and 2 maps were taken when the spacecraft position was north of the equator). This warm feature is also seen in acetylene (C_2H_2) and ethane (C_2H_6) emission, demonstrating that at 1300 cm^{-1} we are witnessing anomalously warm temperatures rather than nonthermal emission from stimulated methane lines.

Coming back to the troposphere, we can produce a rough measure of the ammonia gas distribution by mapping the difference between the brightness temperatures characteristic of (a) a region strongly influenced by ammonia rotational lines and (b) a nearby continuum. The result is a map which is reminiscent of the deeper tropospheric temperatures shown in Fig. 1, except inverted. The strongest absorption is near the equator with a slow decrease toward higher latitudes. On the other hand, taking the difference between this continuum, which is also sensitive to the presence of ammonia ice, and a spectral radiance nearby which is not so influenced by ammonia ice reveals a very different structure--one that is more reminiscent of the $5\text{-}\mu\text{m}$ structure. This would imply that the horizontal distribution of ammonia ice particles is strongly correlated with the spatial structure of clouds deeper in the atmosphere, to which the $5\text{-}\mu\text{m}$ radiance is sensitive.

Between 1979 and 1984, observations were made from Kitt Peak National Observatory and the NASA Infrared Telescope Facility with angular resolution which corresponded to spatial scales of 7000-14000 km at Jupiter (e.g., Caldwell et al., 1979; Caldwell et al., 1980; Caldwell et al., 1983). Figure 2 shows a summary of some of these scans of the central meridian across the disk. For the filtered radiometry at $17.8\text{ }\mu\text{m}$, we are sensitive to temperatures near the 200-mb level, and at $7.8\text{ }\mu\text{m}$ to stratospheric temperatures near 10-50 mb. In 1979, the 200-mb temperatures in the northern hemisphere were noticeably warmer than the south, but by 1983-1984 the south was just a little bit warmer than the north. Keeping in mind that Jovian autumnal equinox (for the northern hemisphere) was in late 1979, it appears that seasonal temperature changes lag the insolation cycle by about three years, consistent with radiative equilibration. Note that the cold region appearing at the equator in 1980 is consistent with the broadening of the visually bright region around the equator. At $7.8\text{ }\mu\text{m}$, the three-banded structure observed by Voyager persists through 1981, but in 1982 things really start to break up. Bands disappear or change latitude position. Also note that seasonal temperature adjustments are quite clear, with the north warmer than the south in 1979 and the opposite in 1984.

Maps of the planet began crudely in 1983 using facilities at the NASA Infrared Telescope Facility, and we are fortunate that the telescope operation was improved by the creation of more efficient mapping software. Banded structure is observable at $17.8\text{ }\mu\text{m}$ (Fig. 3A). At longer wavelengths, consistent with the Voyager IRIS results, the contrast between regions tends to disappear.

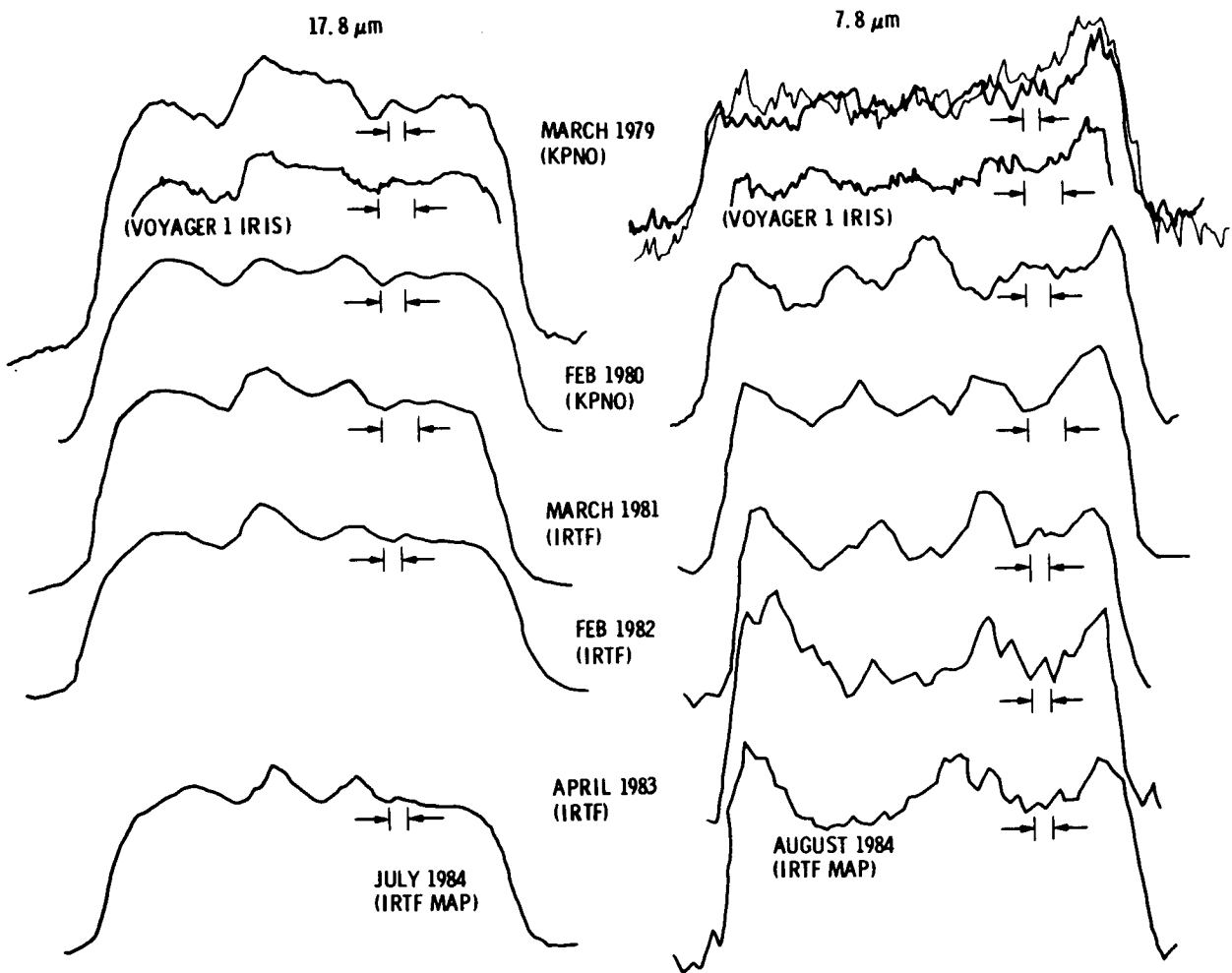


Figure 2. Earth-based scans of the Jovian central meridian near $17.8\ \mu\text{m}$ and $7.8\ \mu\text{m}$ between 1979 and 1984. South is to the left and north to the right. An element of spatial resolution is indicated schematically for each plot. No scan for $17.8\ \mu\text{m}$ was available for 1983. Radiation at $17.8\ \mu\text{m}$ and $7.8\ \mu\text{m}$ are sensitive to temperatures near 200 mb and 10 mb, respectively.

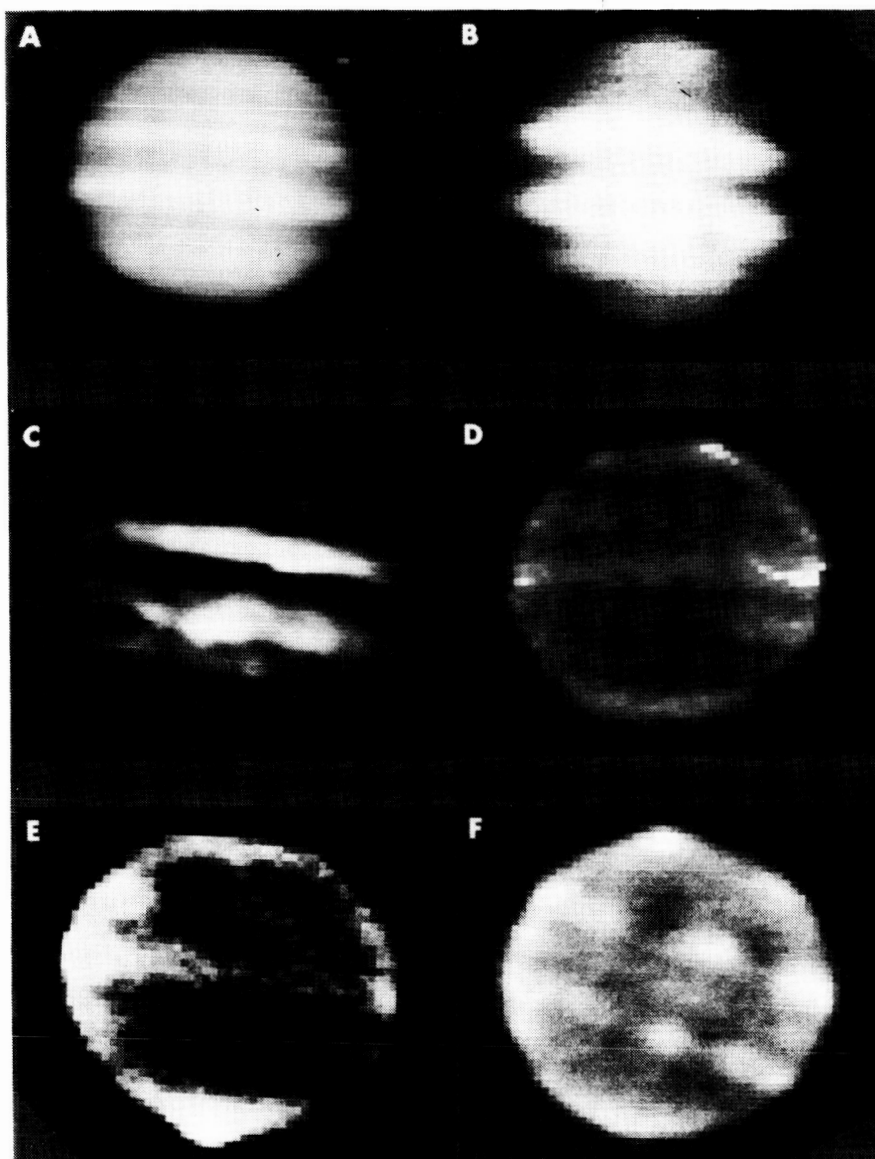


Figure 3. Thermal maps of Jupiter in 1984 and 1985. (A) 17.8- μm map made on 1984 July 23 with System III longitude of the central meridian (LCM) = 344 deg at the mid-point of the map observation. Callisto appears at the upper right. (B) 8.9- μm map of 1984 June 4, LCM = 210 deg, sensitive to the distribution of NH_3 ice clouds. (C) 5- μm map of 1984 April 26, LCM = 148 deg, sensitive to the distribution of NH_3 ice and deeper clouds. (D) 7.8- μm map of 1984 June 7, LCM = 322 deg, showing prominent south polar emission feature and bright area on rising (left) limb. (E) 7.8- μm map of 1984 August 6, LCM = 222 deg, showing linear feature (distorted by planetary rotation) north of equator toward setting limb. (F) 7.8- μm map of 1984 June 21, LCM = 98 deg, showing mid-latitude bright regions of regular spacings and narrow "filamentary" feature on rising limb. Spatial resolution corresponds to about 5% of the disk in each image, except for 5- μm which is about 3%.

Belt and zone structure, as well as regions such as the Great Red Spot, show up even more clearly in maps of ammonia ice cloud distribution at $8.5\ \mu\text{m}$ (Fig. 3B) or for deeper clouds sensed at $5\ \mu\text{m}$ (Fig. 3C).

One of the most interesting and unexpected results of this mapping work is the appearance of the stratosphere as sensed by $7.8\text{-}\mu\text{m}$ maps (Fig. 3D-3F). In these maps, the limb is brightened as expected, and the familiar three-banded appearance is usually observable. But many changes take place across the disk and in time. Brightenings are associated with both north and south magnetic poles (Fig. 3D), and the bright regions have been tracked while rotating. In the crude partial map in 1983, the equatorial band appeared to be missing, but it had returned by 1984. However, the mid-latitude bands appeared to be missing or extremely faint in 1984 at certain longitudes. Faint features, covering many tens of degrees in latitude and longitude appear occasionally; from time to time they make one limb appear brighter than the other. Usually, however, the limb corresponding to Jovian dawn appears brighter than the sunset limb, for reasons which I don't understand at all. In one map in 1984, a strong linear feature (distorted by the rotation of the planet which takes place during the 40 minutes required to complete a $7.8\text{-}\mu\text{m}$ map) was observed crossing from the equator to about $15\text{-}20\ \text{deg N}$ (Fig. 3E); the feature was not reobserved a month later. (Subsequent to the conference presentation of this paper, the 1985 appearance showed more of these occasional linear-like features, unlike anything else on the planet.) Furthermore, at certain longitudes, bright areas appeared in the mid-latitude bands with longitudinal separations of some $15\text{-}20$ degrees (Fig. 3F). These persisted for time scales on the order of months, although rotated with respect to System III.

Only a few types of variable phenomena will be observable by Galileo, and a strong program of regular Earth-based monitoring in certain spectral regions is recommended for the time frame of the mission to supplement the spectral and global coverage available to Galileo remote sensing instruments. For several years preceding and following the nominal mission, such a program will provide an extended baseline to characterize longer-term variability of observable properties at infrared wavelengths. These properties include temperature, gas composition and cloud structure.

ACKNOWLEDGEMENTS

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DR. FLASAR: During the Voyager flybys the temperatures of the North Temperate Belt between 24 and 30 deg N latitude were warmer and clouded over. I got the impression that it wasn't clouding over anymore or the cloud cover was breaking up, but what were the temperatures doing? Are they still warm in that region relative to cold temperatures just south of 24 deg S?

DR. ORTON: They seem to be: from 19-24 deg, cold, and from 24-30 deg, warm from the influence of the North Temperate Belt.

DR. FLASAR: Did that temperature structure stay the same?

DR. ORTON: Yes, in spite of the albedo difference. But the albedo in the northern part is actually getting darker now? Is that correct?

DR. FLASAR: Yes, it got darker around 1981. Is that right Reta?

DR. BEEBE: Yes.

DR. ORTON: Although it is hard to see with the resolution we have which is just 10% of the disk.

MS. CUNNINGHAM: You say that the absorptions occur at different levels in the atmosphere. What levels are you actually probing? Is it mostly stratosphere or is it the troposphere?

DR. ORTON: In the far-infrared, we are probing clouds in a spectral region near 245 cm^{-1} . In the absence of a cloud this would be sounding a level near 800-900 millibars.